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THE EFFECT OF WEIGHTLESSNESS AND DECREASED GRAVITATION

Professor Ye. A. Kovalenko

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16. Abstract

Effects of weightlessness and diminished gravitation are discussed as reflected in data obtained from terrestrial simulated experiments and from spaceflight data. Conclusions are drawn to the effect that weightlessness causes extensive metabolic and functional changes in both human and animal organisms. Weightlessness is one of the primary factors causing detraining as an insurmountable problem and success has been achieved in preconditioning astronauts for weightlessness. The disadvantages of aircraft simulator experiments are pointed out as are many problems in this field which yet remain unsolved.

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THE EFFECT OF WEIGHTLESSNESS AND DECREASED GRAVITATION

Professor Ye. A. Kovalenko

Among the factors which affect the living organism in spaceflight, the most important and least studied is the effect of weightlessness. As experience already accumulated in world science shows, the short term effect of weightlessness over the course of several days can exert a comparatively small negative influence on the organisms of man and animals; this effect rapidly passes following return to the Earth. In the opinions of most investigators, weightlessness can acquire particular significance under conditions of long term spaceflight and immediately after it. /312*

The force of attraction or gravitation exists between any heavenly bodies. It is directly proportional to the mass of the mutually attractive bodies and inversely proportional to the distance between their centers.

It is necessary to distinguish two concepts of weightlessness. The first is that weightlessness is caused by an extremely sharp decrease in the effect of the force of the Earth's gravitation, say at the center of the Earth or an adequately remote distance from our planet in interstellar space. This is so-called static weightlessness. Practically, a state of static weightlessness with nearly complete weakening of the force of action of terrestrial gravitation can occur at a distance from the surface of the Earth more than 37,000 to 38,000 km.

Another type of weightlessness appears in the case of a spaceflight aboard satellites and orbit around the Earth or around other planets at a comparatively near (200-500 km) distance from them. In this case, the satellite itself and all the objects aboard the satellite experience a unique equilibrium of the force of terrestrial attraction and centrifugal force of the rotating satellite. In these cases, so-called dynamic weightlessness appears.

*Numbers in the margin indicate pagination in the foreign text.

From the viewpoint of physics of processes, static and dynamic weightlessness, obviously, are entirely equivalent; from the viewpoint of biological effect of these two types of weightlessness, the question is not entirely clear.

Gravitational fields, proceeding from the unified field of theory, can apparently have several common characteristics with electromagnetic fields whose effect on living biological objects has already been accurately established and which has recently begun to be particularly intensively studied both in our country (A. L. Chizhevskiy, 1964, 1969; Yu. A. Kholodov, 1966; Yu. I. Novitskiy, 1967; A. S. Presman, 1968, and others), and abroad (Reno, Beischer, 1966; Lorenz et al., 1967; Michaelson, 1967; Busby, 1968, /313
and others). Therefore, one probably cannot completely exclude a certain influence of gravitational fields as such and moreover, of its combined effect with electromagnetic fields on the living organism. Together with this it is necessary also to take this into account in case of man's possible travel beyond the gravitational and magnetic fields of the Earth for a long period of time.

The development of life on the Earth began in the primeval world ocean. Under conditions of existence in the aqueous medium, the effect of gravitation on the inhabitants of the seas and oceans was maintained, but pertained basically to an effect on the internal structures and organs. The organism as a whole was located as it were in a suspended condition, in other words, in a state of partial weightlessness. Hence, the prolonged stage of evolution of the animal from the simplest monocellular organisms to fishes occurred under conditions of sharply diminished effect of the force of weight.

The first step from the state of partial weightlessness occurred with alteration of the medium of habitation and the departure of living beings from water to dry land. It was in fact in this period in the development of the animal world that qualitatively new changes occurred. For overcoming the force of gravitation more improved and powerful development of the skeleton and muscular systems were required and new, higher energetic requirements were made. Consequently, a restructuring of the production of energy in the organism occurred and the role of aerobic processes as energetically more suitable increased. There was significant improvement in the method of delivering oxygen to the tissues during the transition from gill breathing to lung breathing, including restructuring of circulation, increase in the capillarization of tissues, development of the system of hemopoiesis, etc. The content of oxygen in water at 20° is about 6.5 ml/liter, while in air it is 210 ml, i.e., more than a 30-fold increase. Under these conditions maximum improvement and hastening of function of methods of delivering oxygen to enzymatic systems of the tissues were required. The transition to dry land actually significantly increased the consumption of oxygen by animals. In this regard, great interest is posed by the investigations of P. A. Kurzhuyev (1964), which show that in the course of evolution, proportional to overcoming the forces of gravitation, more intensive development of bone marrow and hemoglobin goes forward. It is entirely obvious that one should consider that proportional to the ever more improved overcoming of the force of terrestrial gravitation by living organisms, higher energetic demands grew. With the appearance and development of particularly large species of animals, and, which is important, vertically moving animals tall in stature, with greater hydrostatic fluid pressure in the vertical blood vessels of the organism, among a number of factors of the external environment terrestrial gravitation came to acquire ever more important significance. One of the convincing pieces of evidence of the necessity of creating high blood pressure for overcoming the force of terrestrial gravitation are the data of Gauer (1963), which showed that in the giraffe 5-6 meters tall systolic pressure is 375 and diastolic pressure is 230 mm Hg.

One should recognize that forces of gravitation have a great role as a factor under whose conditions biological systems developed and improved.

Therefore, it is entirely natural to suggest that a long term study of living beings under conditions of weightlessness entirely unusual for them will probably have some effect on them. At the same time, we have extremely scattered data in this realm and it is extremely difficult to obtain new facts as the result of the great complexities involved in creating weightlessness under terrestrial conditions.

Simulating Conditions of Hypogravitation and Weightlessness

For successfully solving a number of problems concerning the influence of weightlessness or diminished gravitation on the organism it is necessary to simulate this condition under terrestrial conditions. However, on the Earth it is extremely difficult to create long term weightlessness and its effect on the organism can be only partial. /314

We shall now examine certain possible methods of such partial simulation.

1. A very short term condition of weightlessness (a few seconds) can be obtained at the beginning of free fall when air resistance does not yet have an effect due to the initial low velocity of the falling body. But proportional to the increment in velocity of fall, air resistance becomes significant and the creation of weightlessness, say during an extended parachute jump, is to a significant extent limited. In the capacity of terrestrial devices for partially obtaining hypogravitation during rapid descent downward, one can use high velocity elevators of tall buildings. At the very onset of rapid descent of the elevator compartment, one can obtain a short term significant decrease in weight. In the opinion of V. S. Gurfinkelya et al. (1959), who studied coordination of movements during descent in a high altitude elevator, it is quite convenient to conduct the experiment in an elevator since there one can place the necessary instruments as well as the subject animals. The duration of the time of partial loss of weight can be increased if the elevator is stopped during ascent and then the descent begins at once. In these cases success was attained in obtaining loss of weight of 50-90% (V. Borisov, O. Gorlov, 1961).

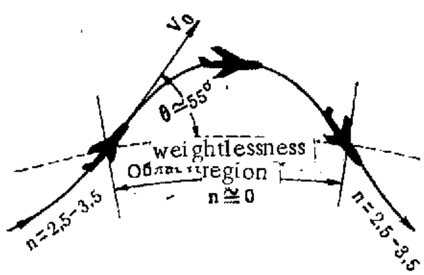

Figure 65. Diagram of Aircraft Flight Along a Parabolic Curve with the Goal of Creating Partial and Complete Weightlessness.

A longer condition of weightlessness can be created during the fall of the compartment or car containing the experimental objects in special U-shaped devices -- gravitrons. The idea of using such a U-shaped pipe with a car moving in it was suggested as early as 1895 by K. E. Tsiolkovskiy, while in

1957 it was developed in detail by the American engineer Walten. But even with a gravitron height of 250 m (one-half the height of the Ostankinskoy television tower) weightlessness could be achieved only for 14 seconds, while in this U-shaped cube one had to remove all of the air in order to prevent its resisting the falling cabin. Such equipment is extremely large and costly and the time of obtaining weightlessness in it is extremely slight. Obviously, therefore, the project of creating such a gravitron has not been realized up to our time.

2. In 1928, Strughold first began to study weightlessness in aircraft during flight over a Kepler parabola. During this process the aircraft makes a unique "climb" (Figure 65). In such a maneuver the aircraft creates a force directed opposite that of terrestrial gravitation. A somewhat longer condition of weightlessness appears (for a period of 40-60 seconds). However in these cases, before and after the state of weightlessness, g-forces appear whose after-effect to a significant extent mask the influence of short term weightlessness itself. The advantage of this type of weightlessness simulation is the possibility of placing an entire laboratory in the aircraft. /315
There is already a large number of investigations of such short term weightlessness conducted both in our country (Ye. M. Yuganov et al., 1961; I. I. Kas'yan, 1962; V. I. Yazdovskiy et al., 1964; P. K. Isakov et al., 1964; L. A. Kitayev-Smyk, 1963; I. I. Kas'yan et al., 1965, 1967, and others), and abroad (Ballinger, 1952; Gerathewohl, 1954, 1956; Beckh, 1956; Lomonaco, Scano, Rossanigo, 1960; Mallan, 1956; Burch, Gerathewohl, 1960, and others). Creating weightlessness during flights along the Kepler parabola is widely used for revealing characteristics of reaction to weightlessness with the goal of determining individual sensitivities of cosmonauts and also for conditioning them. In all these cases weightlessness is simulated usually for less than a minute.

3. Significantly long duration of weightlessness is attained during vertical flights of high altitude rockets. During the flight of a rocket upward, g-forces act on the organism. After the operation of the engines of the rocket is complete and the highest point of flight is attained, fall of the rocket's nose cone begins. From the moment of rocket engine switch-off,

to the time of entry into the dense layers of the atmosphere, a state of dynamic weightlessness continues. In the Soviet Union a large number of such investigations aboard rockets with flights of dogs, rats, mice and other biological objects to an altitude ranging from 110 to 473 km were carried out (B. G. Bugrov et al., 1958; A. M. Galkin et al., 1958; I. I. Kas'yan, 1962, 1963; V. V. Parin et al., 1962). During flights to an altitude of 110 km weightlessness lasted about 3 minutes, during a flight to an altitude of 212 km -- about 5 minutes, and with a flight altitude of 450-473 km -- about 9 minutes.

4. In recent years the number of studies in which a partial state of weightlessness is simulated under conditions of immersing a man in liquid with a specific gravity near the specific gravity of the body has sharply grown. However it is necessary clearly to understand the extremely significant qualification of such a simulation of the state of weightlessness. It is important to bear in mind that forces of gravitation act on all parts of the body, on each organ, tissue and cell. Under ordinary conditions the force of gravity, acting on the organism, is held in a state of equilibrium by the surface forces of pressure points. Under the influence of these forces the entire organism and all of its parts experience a certain pressure and deformation which is preceded by them as the effect of weight.

During immersion in a liquid with a specific gravity near that of the mean specific gravity of the body, the effect of the force of gravity pressing the body to the Earth is counteracted by forces thrusting the body from the water. There occurs a more even and ubiquitous distribution of force over the entire body surface. Here a condition of suspension or partial simulation of weightlessness is created. However, all of the internal organs continue to experience the effect of terrestrial gravitation. This method of partially simulating weightlessness has begun to be used more widely in recent time (I. F. Chekirda, 1969; Hood et al., 1968; McCally et al., 1969, and others), since it is comparatively simple and does not require expensive equipment.

To simulate weightlessness, Hunt (1967), while immersing 12 subjects in water for 6 hours, studied changes of diuresis and orthostatic instability.

Liquid silicon is considered the most suitable type of fluid for simulating weightlessness and for creating neutral buoyancy (Webb, 1966).

5. In recent times reports have appeared concerning the creation of special complex trainers making it possible to make the most varied movements with a diminished effect in the force of gravity. Usually only partial decrease in weight (from 12.5 to 50%) is attained in these cases. Hewes and Spady (1964) developed a special trainer with an inclined surface at an angle /316 to the vertical of 9°47'. The subject was suspended in it on special straps which were affixed to a distributing plank located on top of the device. Gravitation equal to one-half terrestrial gravitation was created when walking along the sharply inclined plane of the trainer with the treadmill mounted in it. In such trainers, in principle, a corresponding body counterweight is used (reminescent of the elevator compartment counterweight). The man is dressed in a compartmented suit affixed to the cabin and connected via blocks to the system of counterweights. The point of suspension is at the center of gravity of the subject. The latter can move about over three axes, i.e., freedom of movement here is extremely great.

6. The following method of simulation, not weightlessness, but only certain elements of it is an application of strict horizontal location of the body during a long term stay in bed with sharp limitation of movements, i.e., creating long term hypokinesis. In this case there is a decrease in the effect of hydrostatic forces and load is removed from the skeletal-muscular system, i.e., long term muscular hypodynamia is created with disorders of the protein and calcium metabolism in the bones and with deconditioning of the cardiovascular system (A. V. Korobkov, 1967; L. I. Kakurin, 1968; Ye. A. Kovalenko et al., 1970; Brannon, 1963; Lamb, 1965; Miller, 1964; Birkhead, 1963; Vogt, Johnson, 1967, and others).

During a study of long term hypokinesis (over a period of 100-170 days), a polymorphous picture of significant changes in metabolic processes in the organisms of animals and a sharp decrease in the working capacity were established (Ye. A. Kovalenko et al., 1970, 1971).

During a strict evaluation of all experimental paths of creating weightlessness, it is not difficult to conclude that all these methods have serious inadequacies and that the most perfect method of studying this state is by utilizing weightlessness obtained in real orbital flights aboard artificial satellites of the Earth, in which one can create a state of dynamic weightlessness most fully and for a practically unlimited period of time. Under the conditions of terrestrial experiments, one can simulate only certain aspects of the effect of weightlessness on the organism, or one can obtain weightlessness for very short periods of time.

	I	II	III	IV	V
Dynamic weightlessness or Decrease in the force of the Earth's gravitational field	Stress reactions caused by transition from g-forces to the unusual situation of weight loss	Partial accustomment and adaptation to the new conditions	Prolonged, gradually increasing effect of weightlessness on all functions of the organism	Effect of g-forces and terrestrial gravitation	Residual phenomena of the effect of weightlessness
	"First encounter with weightlessness"	"Accustomment to weightlessness"	"Effect of weightlessness as a function of action time"	"Repeated increase in gravitational effects"	"Reparation period"
	First 24 Hours	4-7 days	Over 10-14 days	First hours and days on the Earth	1-2 months

Stages of the Effect of Weightlessness on the Organism Under Conditions of Spaceflight

The stages of the effect of weightlessness on the organism can be represented by the diagram (see page 316). /317

First stage. Transition process from take-off g-forces to weightlessness. This continues until the end of the first day. At first stress reactions can appear caused by the transition from g-forces to the unusual situation of weight loss. Basically, this period does not cause clearly pronounced disorders.

The Soviet cosmonaut Yu. A. Gagarin, and later V. F. Bykovskiy estimated the state of weightlessness as a state which does not cause unfavorable sensations. However, in a number of cases vestibular and vegetative reactions are possible, as well as illusions of an upside down body attitude, sensation of blood rushing to the head, and sense of discomfort. These disorders were observed among the cosmonauts G. S. Titov, V. V. Tereshkova, B. B. Yegorov, and others (N. M. Sisakyan, 1965; P. V. Vasil'yev, Yu. M. Volynkin, 1965; Ye. M. Yuganov, A. I. Gorshkov, I. I. Kas'yan, 1965; O. G. Gazenko, A. A. Gyurdzhian, 1965; I. I. Kas'yan, V. I. Kopanev, 1967, and others), and also among the American astronauts (Berry, 1969).

Second stage. Accustomment to weightlessness. This period occurs without particular disorders. The defunctional deviations which at first appear gradually diminish, however the duration of this period has not yet been accurately established.

During the flights of the Soviet cosmonauts A. G. Nikolayev, P. R. Popovich and V. F. Bykovskiy, proportional to their stay in weightlessness, gradual adaptation developed. Thus, pulse frequency of V. F. Bykovskiy at the end of the first day of flight was 101 ± 9.2 beats per minute, on the second day -- 63 ± 2.5, on the fourth day -- 58 ± 2.4, on the fifth day -- 57 ± 5.6 beats per minute; frequency of respiration in the first days in this cosmonaut was 24 ± 5, and on the fifth day -- 17 ± 1.4 per minute (I. I. Kas'yan, V. I. Kopanev, V. I. Yazdovskiy, 1965). Similar phenomena of adaptation in approximately the same periods also occurred among the American astronauts MacDivitt and White during flights aboard the Gemini-4 spacecraft (Carlson, 1967; Berry, 1966).

Third Stage. Long term existence under conditions of weightlessness. This period is most important for study, since data are limited to flights of American astronauts on the Gemini-7 spacecraft over a period of 14 days. The longest flight in space was made in our country aboard the Soyuz-9 spacecraft by A. G. Nikolayev and V. I. Sevast'yanov (18 days). Earlier, a long term biological experiment in space was carried out during the flight of two dogs -- "Veterka" and "Ugol'ka" aboard the biosatellite "Kosmos-110" over a period of 22 days.

Available data indicate the certain adaptation to long term weightlessness. However, up to what time this process will continue and at what level it will stop are at present unclear. It is entirely possible that the long term existence of living objects under conditions of extinguishment of the force of gravitation causes certain changes in the structure and metabolism in varied physiological systems (primarily in the skeletal and muscular tissues). It is extremely probable that the noted changes will become ever more pronounced with the passage of time. Apparently, the search for these temporal periods of the effect of weightlessness should be one of the chief tasks of investigations of the effect of weightlessness on the organism.

Another factor is of no less important significance. The onset of /318 adaptation to long term weightlessness can lead to detraining of the organism to conditions of terrestrial life. This factor can be extremely important during return of cosmonauts to the Earth.

The succeeding fourth and fifth periods are basically periods of the after effect of weightlessness but are organically linked with this state and are the peak of the effect of weightlessness on the organism.

Fourth stage. The effect of g-forces during braking of the spacecraft and during its entry into the dense layers of the atmosphere poses difficulty, since after adapting to prolonged weightlessness the organism once again must encounter the effects of g-forces which exceed by several times the force of terrestrial gravitation. This is why disorders of the systemic and regional circulation are possible in the force.

Fifth stage. The period of residual phenomena of the effect of long term weightlessness. Judging by already available data, after a 34 hour stay in weightlessness (in 1963), aftereffects were observed for a period of 18 hours, while during an 8 day stay in weightlessness aftereffects were noted for more than 30 hours in the American astronaut Gordon Cooper (the former occurring in 1963 and the latter occurring in 1965) (Dietlein, 1964; Lamb, 1964; Berry, 1966). As Berry officially reported (1966, 1967), after a 14 day flight aboard Gemini-7, no particularly great difference in the orthostatic resistance in astronauts F. Borman and D. Lovell was noted in comparison with astronauts of the Gemini-5 spacecraft, although the flight of the latter continued for a period of time almost twice as short as that of the former.

Signs of disorders with respect to the cardiovascular system as the result of its detraining and a significant deterioration in working capacity were observed among astronauts after flights aboard the Apollo spacecraft. The noted disorders were maintained for a period of 24 to 36 hours (Berry, 1970).

Extremely interesting data are cited in the work of Ye. I. Vorob'yev et al. (1970). After an 18 day long flight aboard the Soyuz-9 spacecraft, sensations of weightiness were observed in cosmonauts A. G. Nikolayev and V. I. Sevast'yanov. Over the course of 3 hours after the flight they could not maintain a vertical posture. Changing from the line position to the sitting position or the vertical position was accompanied by dizziness, weakness, and an increase in cardiac contractions. Even in the line position, the cosmonauts felt "pressed down" into the bed, they felt an unusual increased weight of the head, extremities, and even the internal organs. This state continued for about 2-3 days.

What is the maximum period of safe stay for man under conditions of weightlessness today? Gerathewohl (1964) considers that this period should not exceed 2 weeks, while in Berry's opinion (1966, 1967, 1970), one can stay in weightlessness for up to 30 days.

The General Picture of Changes

To construct an exemplary diagram of the pathogenesis of the effect of weightlessness on the organism it is primarily necessary to determine what the main pathogenic factor is. Under conditions of usual life on the Earth, under the influence of the effect of gravity on the organism, certain deformations occur. Compression of the whole organism appears which is well illustrated, for example, by the known decrease in body length in the vertical posture of 3-6 cm, in comparison with that of the horizontal. Deformation is manifested in the form of compression of the ligaments, compression of the cartilage, distention of the walls of blood vessels under the influence of the blood's weight, compression and movement of the skeletal elements and of the very parenchyma of the organs and tissues, movement of the liquid media in the /319 intercellular lumina, etc. The magnitude of deformation in various regions of the organism and its structures can fluctuate from centimeters to microns. In the lower regions of the body it is more pronounced, since the regions of the body located higher compress those below. In weightlessness, during disappearance of the effect of body weight, deformations in the organism also disappear. Consequently, the basic essence of the effect of weightlessness on the organism is the removal of deformations. Inasmuch as gravitational forces are massive forces, their disappearance causes a massive ubiquitous effect of deformation elimination.

Thus, the main pathogenic factor of the effect of weightlessness is the disappearance of deformations in the organism. As a result of this there is a decrease or change in afferent impulsation from the various internal receptors of regions constantly signalling the central nervous system concerning the effect of the force of gravity on the organism. Moreover, displacement of liquid media in the organism occurs with partial change in the shape, configuration and location of specific organs and a decrease in the pressing and compressing effect on the supporting structures of the organism. All of this, naturally, causes certain changes in the functions of various physiological systems.

The concept "deformation" has long existed in classical physics, but it /320
has not yet found the required deep understanding and application in medicine and biology. However, in the realm of gravitation biology this concept is acquiring particular significance, since it bares the essential cause of the entire chain of aftereffect disorders during change or disappearance of gravitation.

The removal of deformations leads to a systemic decrease in functional load on the entire organism; there is change in the work of the muscles and the cardiovascular system; water, mineral and energetic metabolisms are disrupted; it causes restructuring of bone tissue, etc. The overall effect of long term weightlessness on various functions and systems of the organism is schematically depicted in Figure 66.

Vestibular and sensory changes. In the period of orbital flight, sensory and vegetative disorders appeared in certain Soviet and American cosmonauts and astronauts. One can isolate three groups of people according to the character and expressions of these reactions. The first group includes persons in whom working capacity is not diminished in a state of weightlessness and who experience a favorable sense of weakening for lightness as the result of loss of their own body weight (Gerathewohl, 1956; Ye. M. Yuganov et al., 1961).

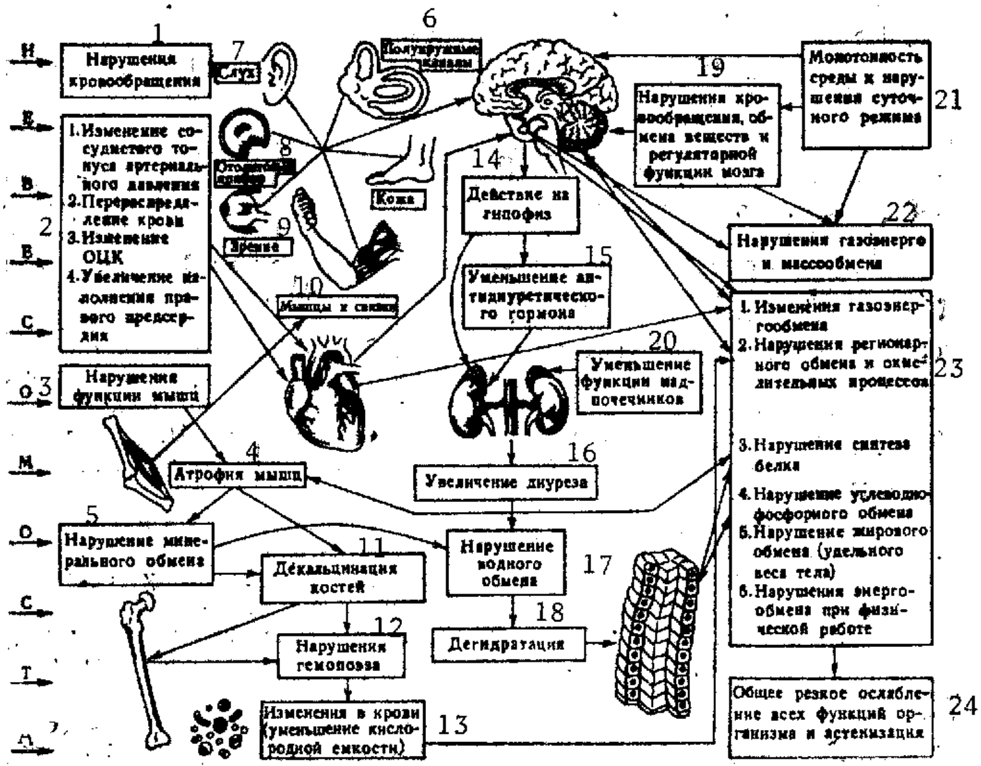

Figure 66. Suggested General Diagram of the Pathogenesis of the Effect of Long Term Weightlessness on the Organism. 1, Circulatory disorders; 2, 1. Change in vascular tonus and arterial pressure., 2. Redistribution of blood., 3. Change in overall circulation of blood., 4. Increase in filling of the right ventricle or auricle.; 3, Disruption of muscular function; 4, Muscular atrophy; 5, Disruption of mineral metabolism; 6, Semicircular canals; 7, Hearing; 8, Otolith organ; 9, Vision; 10, Muscles and ligaments; 11, Decalcination of the bones; 12, Disruptions of hemopoiesis; 13, Changes in the blood (decrease in oxygen volume); 14, Effects on the hypophysis; 15, Decrease in antidiuretic hormone; 16, Increase in diuresis; 17, Disruption of water metabolism; 18, Dehydration; 19, Disorders of circulation, metabolism, and regulatory function of the brain; 20, Decrease in adrenal function; 21, Environmental monotony and disruption of the diurnal regime; 22, Disruption of gas energetic and mass metabolism; 23, 1. Changes in gas energetic metabolism., 2. Disorders of regional metabolism and oxidation processes., 3. Disorders of protein synthesis., 4. Disorder of carbohydrate-phosphorus metabolism., 5. Disruption of lipid metabolism (specific gravity of body)., 6. Disruption of energetic metabolism during physical work.; 24, General sharp weakening of all functions of the organism and development of asthenia.

The second group includes people who experience a sensation of free swimming through the air in the period of weightlessness, and who sense a pronounced feeling of spinning or rotation of the body in an undetermined direction, with their heads hanging downward. The indicated phenomena are accompanied by enxiety, loss of orientation in space, and by a sensation of discomfort (P. V. Vasil'yev, Yu. M. Volynkin, 1965; O. G. Gazenko, A. A. Gyurdzhian, 1965; I. I. Kas'yan, V. I. Kopanev, 1967).

The third group includes people in whom the unfavorable phenomena develop significantly more rapidly and conclude with pronounced symptoms resembling seasickness. This leads to temporary decrease or even loss of human working capacity (K. L. Khilov, 1939; Gerathewohl, 1956; G. L. Komendantov, V. I. Kopanev, 1962; Hauty, 1960; V. I. Yazdovskiy et al., 1964). What are the causes and mechanisms of such disorders?

Many investigators suggest that in connection with weight loss, the otoliths cease to fulfill their role as stimulators of the peripheral neural instruments of the vestibular apparatus and since a functional link exists between the otoliths and the cupulo-endolymphatic system, being expressed in suppression of the semicircular canals, the latter, "freed" from the suppressing effects of the otoliths become more sensitive to adequate stimuli (Schock, 1960, 1961; G. L. Komendantov, V. I. Kopanev, 1962; Graybiel, Kennedy, 1964). Another viewpoint is supported by E. M. Yuganov (1963, 1964, 1965), who considers that in weightlessness no functional deviation of the otolith apparatus occurs, but rather an unusual "minus-stimulus" for the otoliths appears. Some investigators (Margaria, Gualtierotti, 1962; Margaria, 1963; Gualtierotti, 1963) suggests that the vestibular disorders in dynamic weightlessness do not depend upon the absence of stimulation from the sense organs since spontaneous electrical activity of the labyrinth during weightlessness is maintained, and threading through the vestibular nerve disrupting the vestibular apparatus and nerve centers does not cause those symptoms which are observed in weightlessness. There were no serious disorders of muscular coordination characteristic for persons with destroyed labyrinth in G. S. Titov, although he did have vestibulo-vegetative disorders (G. L. Komendantov, V. I. Kopanev, 1962).

In the process of long term exposure to weightlessness, a gradual decrease occurs in the vegetative disorders caused by vestibular disruptions /321

(V. V. Parin et al., 1965; Ye. I. Vorob'yev et al., 1970; Deitlein, L. E. 1964 and others). According to the data of Berry (1966, 1967), in astronauts F. Borman and D. Lovell illusory sensations of an upside down position of the body passed after one day of flight. Taking this into account, particular significance is acquired by a careful check when selecting cosmonaut candidates. This check should be for vestibulo-vegetative stability and also for good preliminary training (Ye. M. Yuganov et al., 1965). A bright illustration of this concept is the flight, exit and successful work in open space of A. A. Leonov. In the opinion of A. A. Leonov and V. I. Lebedev (1965), particular significance during orientation in movements in weightlessness and open space is primarily acquired by vision, then by tactile, and finally by musculo-tendonous senses. Lesser significance attaches to signalization from the vestibular and interoceptive analyzers.

For a more detailed disclosure of the mechanism of vestibular disorders it is necessary to establish the functional links with different vegetative changes. In this regard, studies carried out by B. N. Klosovskiy and Ye. N. Kosmarskaya (1961) are of great interest. In these studies the influence of vestibular receptors on the characteristic of the brain's circulation were clearly shown. However, up to now the problem of the mechanisms and character of links between the effect of weightlessness, vestibular disorders, and the vegetative disorders caused by them has not been decisively resolved.

The cardiovascular system and water metabolism. One of the fundamental pathogenic elements in the effect of weightlessness on circulation is the disappearance of hydrostatic blood pressure in the blood vessels, particularly those located along the vertical axis of the body. Under ordinary terrestrial conditions, in the lower half of the body, in the blood stream, besides the pressure created by the work of the heart, there is pressure of the weight of the vertical column of blood, i.e., hydrostatic pressure. In a man of average height, 175 cm, blood pressure in the blood vessels at the level of the soles of the feet will be 100 mm Hg higher, and in the brain about 30-40 mm Hg lower than it is at the level of the heart. The elastic walls of the arterial tree in the lower half of the body should constantly create corresponding "counter pressure". This also to a significant degree pertains to the smallest arterioles, and particularly to the capillary tree, vast in its area, in which blood pressure, although it is much lower, also includes the hydrostatic component. In the venous portion of the tree hydrostatic pressure of the column of venous blood is directed against its flow to the heart, and as it were interferes with venous return of blood. The latter should always be well compensated for by tonus of the walls of the veins, muscular contractions which compress the veins and by the presence of venous valves, the sucking effect of the thoracic cavity and the small residual systolic pulling action of the heart passed on to the portion of blood moving through the capillaries. In the upper half of the body, on the other hand, the slight magnitude of the hydrostatic column of venous blood creates a force enabling the return of blood to the superior vena cava into the right auricle. The above is partially illustrated in the diagram (Figure 67).

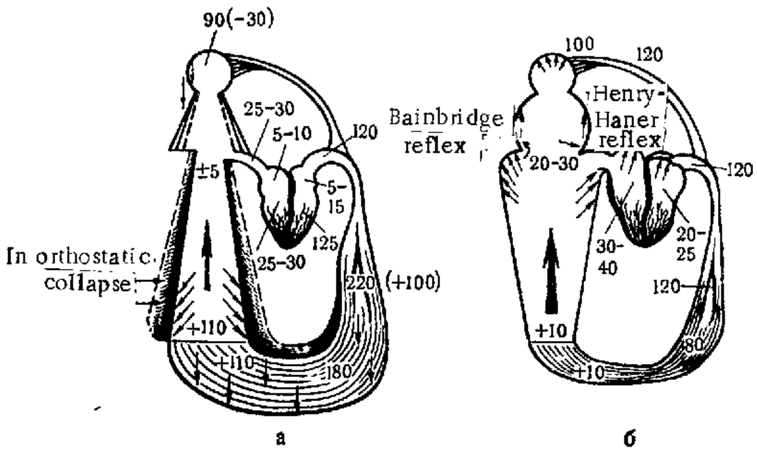

Figure 67. Diagram of the Effect of Hydrostatic Pressure and Weightlessness on Circulation. a, Effect of hydrostatic pressure; b, Effect of weightlessness. Numbers show blood pressure in various regions of the vascular bed.

When a man moves from the vertical posture to the horizontal, i.e., when he simulates weightlessness (Vogt, 1966, 1967; V. S. Georgiyevskiy, 1965; Lamb et al., 1964, 1965), the factor of hydrostatic pr pressure almost entirely disappears, since the primary large main blood vessels are located along the vertical axis of the body. Under these conditions, the blood volume of the legs decreases by nearly 50%, the extremely significant pressure on the blood vessels of the lower half of the body is removed and blood supply to the brain increases by almost 20% (Mayerson, 1942; Scheinberg, Stead, 1949; Lamb, 1964). This may be the reason why the onset of a state of weightlessness in cosmonauts /322 after the spacecraft's entry into orbit was accompanied by a sensation of blood rushing to the head and reddening of the skin of the face (Ye. I. Vorob'yev et al., 1970). There is a significant increase in the amount of blood flowing in to the heart from the lower part of the body (see Figure 67). According to the data of Lamb (1964, 1965), during change from a vertical posture to a horizontal one, the minute volume of the heart can increase from 4-5 liters per minute and more. If this state continues sufficiently long then detraining of large and extremely large volume regions of the vascular bed ensues, which is usually observed after a long term stay in bed. Upon returning from weightlessness, even in the case of a comparatively short stay in it (Berry, 1966, 1967, 1969, 1970), or when taking a vertical posture after a long term stay in a horizontal posture, as a rule, a threatening phenomenon of orthostatic hypotension develops when a significant portion of the blood vigorously enters the detrained vascular tree of the lower half of the body which has lost its ordinary tonus (see Figure 67). Under these conditions regional regulation of the cardiovascular system is in no state rapidly to correct the necessary blood flow to the brain. Anemia of the brain can ensue with loss of consciousness, i.e., a state of orthostatic collapse with decrease in pulse pressure, an increase in plethora of the legs and a compensative increase in pulse frequency (Lamb, 1964, 1965; Berry, 1966, 1969, 1970, and others) (Figure 68).

The experiments performed on animals after long term hypokinesis, were noted that with a change in the position of the body from the ordinary, horizontal to vertical one, a clear cut but short term decrease in oxygen pressure in the brain tissues occurs. Similar data can be obtained also by the method of electroplethysmograph of the brain in animals and man in the investigations of Yu. Ye. Moskalenko (1967).

One can consider it proven that during orthostatic hypotension, hypoxia of the brain is one of the primary disorders of the organism. The long term redistribution of blood and increase in plethora of the venae cavae, right auricle, blood vessels of the lesser circuit and left auricle which occur in weightlessness could be caused by certain restructurings of the well-balanced interactions of cardiac and vascular reflexes. Specifically, an increase in /323

the role of the Bainbridge reflex can appear. Extremely great significance also attaches to change in the classic reflex from the sinocarotid zones due to an unusual, long term change in redistribution of blood in the upper half of the body. The slowing of pulse and slight decrease in arterial pressure observed among almost all cosmonauts in the first hours of their return to weightlessness makes one also think of this reflex mechanism (N. M. Sisakyan, V. I. Yazdovskiy, 1962; R. M. Bayevskiy, O. G. Gazenko, 1964; P. V. Vasil'yev et al., 1965). The drop in the hydrostatic component of blood pressure on the walls of the lower half of the vascular tree reached a redistribution of the blood in an increase in plethora of the blood vessels of the upper half of the body and right heart and also reflexively (the Henry-Gauer reflex) to plasma walls, decrease in the formed elements, and in the end to a decrease in the volume of circulating blood (Henry, Gauer et al., 1965; N. N. Gurovskiy, A. A. Kiselev, 1968). The mechanism of this chain of disorders is to a great extent unclear, but plans are afoot to trace it further. In the opinion of A. G. Genetsinskiy and his school (1956, 1963), during plethora of the auricle particular significance is acquired by the Henry-Gauer reflex which suppresses the production of antidiuretic hormone (Henry, Gauer et al., 1956). This can lead to an increase in urine excretion, and consequently, to disruption of the /324
water metabolism and to dehydration of the organism (B. D. Kravchinskiy, 1963; E. Kerpel'-Fronius, 1964).

During man's long term stay in the horizontal position, significant redistribution of the blood occurs with an increased influx of blood to the organs of the thoracic cavity. According to the data of plethysmography, 11% of all blood flows from the legs, in 78% of this amount proceeds to the thoracic cavity and only 2% to the animal's organs (Sjostrand, 1963). It is natural that under these conditions there is a sharp increase in the role of the Henry-Gauer reflex. The venae cavae, pulmonary arteries and veins, in left auricle make up the one systemic elastic system whose degree of filling with blood reflects pressure and volume in the left auricle. An increase in this pressure leads to an increase in the elimination of fluid from the organism. The latter was found both in Soviet cosmonauts during flight aboard the Soyuz spacecraft (Ye. I. Vorob'yev et al., 1969, 1970) and among American astronauts after flights aboard the Gemini and Apollo spacecraft. Similar data were obtained in simulation tests on 12 subjects who stayed for a month under conditions of a strict bed rest regime. Even in the first 2-3 days, the total volume of circulating blood decreased by 200-1,300 ml (on the average by 750 ml), the volume of plasma decreased by 550 ml, and the erythrocyte mass decreased by only 180 ml. A decrease in the weight of the subjects at the end of the experiments comprised 2.5 kg on the average (Miller, Johnson, Lamb, 1964).

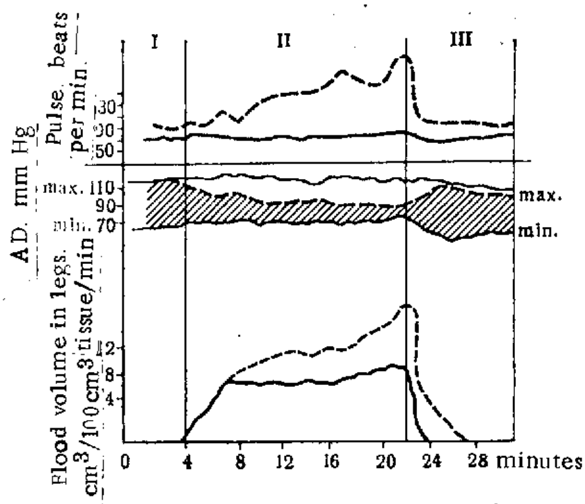

Figure 68. Reaction of Indices of Hemodynamics with Orthostatic Tests on an Inclined Table Before (heavy curve) and after (dotted curve) a Stay in Weightlessness (after C. Berry, A. Catterson, 1967).

I, Period of horizontal posture;
II, Period of vertical posture;
III, Period of horizontal posture.

Upon the elimination of significant amounts of fluid and disruption of the electrolyte balance, changes in the acid-alkali equilibrium of the blood can occur, which was found in dogs after a 22 day long spaceflight aboard Cosmos-110 (A. A. Kiselev, I. N. Kotova, 1967). Subsequently, changes in the production of aldosterone can enter the chain of disorders which have appeared. Ye. D. Ross (1962) considers that in conditions leading to a decrease in the effect of volume of circulating blood, secretion of aldosterone with subsequent retention of sodium in the organism must occur. An increase in the content of sodium in the blood was noted in V. A. Shatalov, B. V. Volynov, A. S. Yeliseyev and Ye. V. Khrunov after their flight (Ye. I. Vorob'yev et al., 1969). This can entail an increase in osmotic pressure of the blood serum at an increase in the secretion of antidiuretic hormone. Retention of water in the organism can lead to compensator increase in the volume of plasma and to the known compensation of dehydration. However, subsequently, with a certain surplus of aldosterone an increase in edemas and the development of a condition of "homeostasis disease" can occur (Cattan, Vesin, 1956).

It is extremely important to take yet another fact into account. Under conditions of the Earth, hydrostatic pressure in the blood vessels in the vertical posture makes possible filtration of fluids from the blood vessels into the tissues. Under conditions of weightlessness, with the removal of hydrostatic pressure, the retention of fluid in the blood stream will occur only because of oncotic and osmotic pressure. The so-called Starling equilibrium is disrupted, i.e., the equilibrium of filtration and inverse absorption of plasma into the capillaries. At first this leads to blood hydremia, but then mechanisms come into effect directed against the excess dilution of the blood, and in the case of an excess of these protective mechanisms, at first the cycle of "hyperadaptation disease" can repeatedly appear. It is interesting that under conditions of long term hypokinesis without the removal of hydrostatic pressure, a certain increase in diuresis and dehydration of the organism occurs all the same in animals (Ye. A. Kovalenko, 1970, 1971).

Both Soviet and Foreign investigators also emphasize the significant weight loss as the result of an increase in diuresis after a stay in weight- /325
lessness (Ye. I. Vorob'yev et al., 1969, 1970; A. D. Yegorov, L. I. Kakurin, 1969; Berry, 1969, 1970 etc.).

An evaluation of already available data obtained during short flights shows that the greatest changes with respect to the cardiovascular system occur in the period of the organism's exposure to g-forces during takeoff and particularly, during descent. In the period of effects of weightlessness itself, notwithstanding a slight normalization of pulse frequency, EKG, and blood pressure, one notes an increase in lability and clear cut instability of these indices (N. N. Gurovskiy et al., 1968; Berry, 1969). During their accomplishment of light work with the dynamometer, cosmonauts V. M. Komarov, K. P. Feoktistov and B. B. Yegorov, during their flight aboard the Voskhod-1 spacecraft, were observed periodically to undergo increased frequency of pulse and respiration; these reactions can be viewed as the result of starting effects of the nervous system at the initial moment of load and subsequent adaptation of circulation through increased oxygen requirements.

During the effect of the g-forces of launch and encounter with the conditions of terrestrial gravitation, readaptation of the function of the cardiovascular system must once more occur. This is the most responsible period with respect to load on the cardiovascular system. This proposition can be very clearly demonstrated using the example of the 18-day long flight of cosmonauts A. G. Nikolayev and V. I. Sevast'yanov aboard the Soyuz-9 spacecraft (Ye. I. Vorob'yev et al., 1970). However, the use of any particular protective measures and training in the process of a long term stay in weightlessness, apparently, can diminish disruption of the hemodynamics in this period if one can see using the example of the flight of astronauts F. Borman and D. Lovell aboard the Gemini-7 spacecraft (Berry, 1966, 1967; Carlson, 1967).

The function of the muscles. In the state of weightlessness there is a significant decrease in load on the skeletal motor apparatus. The entire mass of muscles which formerly countered the force of terrestrial gravitation sharply diminishes its functions under conditions of weightlessness. Ye. M. Yuganov et al. (1963) showed that in weightlessness one observes a sharp decrease in voltage of oscillations and even a picture of bioelectrical quiescence of the "antigravitational musculature". A decrease in muscular activity can be intensified by dressing the cosmonaut in a space suit, and also by the limited space of the spacecraft cabin. All this leads to severe hypokinesis.

According to the data of Rademaker (1962), under ordinary conditions resistance to the force of gravity creates tonic stress of muscles of the lower extremities and inflexible tonic sagging of the trunk and neck. In weightlessness this tonic stress of the muscles can be sharply weakened or gradually can entirely disappear.

With sharp limitation of muscular function significant muscular atrophy can develop. Deitruk (1948) observed muscular atrophy and decrease in the transverse dimensions of the heart in four healthy men after a 6-week long stay in plaster casts. Decrease in muscular tonus leads to venous congestion and it deepens even more the hemodynamic disorders.

In an investigation conducted by Lynch and Jensen (1967) on 44 subjects, it was clearly shown that during a 28-day long period of hypodynamia loss of nitrogen, phosphorus, and a number of electrolytes (sodium, chlorides, calcium, etc.) occurs. Sharp limitation in muscular activity (hypokinesis) of itself causes a broad complex of polymorphic disorders which lead to a sharp decrease in the resistance of the organism to a number of unfavorable factors (A. V. Korobkov, 1962, 1963; A. L. Myasnikov et al., 1963; Ye. I. Chazov, V. G. /326 Anonchenko, 1963; L. I. Kakurin, 1968; Ye. A. Kovalenko et al., 1970, 1971; Graveline, 1963; Lamb, Johnson, 1964).

It is important to take into account that the contractive and ATP activity of the myofibriles are regulated by the concentration of free calcium in the sarcoplasm. Each myofibrillar fiber is covered with an electrically polarized membrane. Contraction is caused by an impulse proceeding along the nerve to the terminus of a layer which is in contact with the fiber. During the passage of the impulse depolarization of the membrane occurs and ions of calcium are liberated along the entire fiber. After the impulse has passed, calcium salts are bound with the sarcoplasmatic chains, i.e., by means of unification of the fine tubules within the muscular fiber (Hill, 1949). Hence, muscular contractions have a direct and extremely intimate link with normal calcium metabolism, which can be significantly disrupted during hypodynamia and weightlessness (see Figure 66).

When analyzing human movements it is conventional to isolate two components: the first -- muscular strength which is a response reaction to the effective mechanical forces, primarily the force of gravity, and the second -- direct locomotor acts. Upon coming into contact with weightlessness there is a change in the influence on both these components. Although under terrestrial conditions with any movement man applies an effort adequate to the effect of the force of gravity, in weightlessness such a stereotype could become a source of error. Cosmonaut A. A. Leonov noted that the criteria for correctness of fulfilling exercises in unsupported space, i.e., after leaving the dock chamber, was evenness in departures and approaches to the lock without sharp jerks or efforts (A. V. Yeremin et al., 1965; I. I. Kas'yan et al., 1966). Man and animals gradually become accustomed to coordinating necessary muscular effort with new relationships of diminished or altered gravitation (P. K. Isakov et al., 1964; Ye. M. Yuganov et al., 1962). But besides this element of force, in movement man also has a fine coordination conditioned by exact information from tactile, visual, vestibular and motor analyzers. The interaction between these analyzers as well as the constant inverse link of the proprioceptive information during movement under conditions of weightlessness can be seriously disrupted. The absence of accustomed tactile sensations and a change in proprioceptive signals coming from the skeletal-muscular or motor-supportive apparatus during free movement in weightlessness lead to discoordination of movement, particularly in the first moments of weightlessness. One observes exaggeration of movements, disruption of fine duplication of commanded muscular efforts, and disruption of coordination of movements. The establishment of new coordinated relationships and active correcting of efforts in the process of goal directed activity and the necessity of maintaining the necessary position of the body relative to surrounding objects and instruments rapidly causes a sense of fatigue (B. B. Yegorov, 1964; K. P. Feoktistov, 1964).

However, with adequately good selection of candidates for cosmonauts and careful training under conditions of weightlessness, man can quite successfully overcome these complex obstacles and can accomplish goal directed movements and work. This is well shown using the example of cosmonaut A. A. Leonov, who carried out complex work in open space.

In experiments performed on dogs after the flight of Kosmos-110, i.e., during the longest stay in weightlessness, a significant decrease in the weight of the animals as the result of an extremely clearer decrease in the muscular mass was clearly shown (N. N. Gurovskiy, A. A. Kiselev, 1968). Under /327 conditions of long term (up to 100-170 day) hypokinesis in the rat, sharp weight loss and pronounced decrease in working capacity were also noted (Ye. A. Kovalenko, 1970). A significant decrease in working capacity was also noted following a 14-day long flight of American astronauts aboard the Gemini-7 spacecraft (Berry, 1966, 1967), and after flight aboard the Apollo spacecraft (Berry, 1969, 1970).

With a decrease in muscular contractions a sharp decrease occurs in the production of adrenaline, and particularly of noradrenaline (B. M. Fedorov, V. S. Nevstruyeva, 1969), which can even more deeply worsen the prolonged loss of vascular tonus and disruption of hemodynamics.

Bone structure and calcium metabolism. In 1892, the anatomist Volf clearly demonstrated the dependency of bone structure, orientation of its structural elements and mass of the substances comprising it on the force and direction of mechanical load. The deforming force causes a change in the structure of the bone necessary to counteract this force. What serves as the signal which causes these or other changes in the bone?

Over the course of the past decade, fundamental discoveries have been made in this field (Bassett, 1956, 1957, 1965). It has been shown that during mechanical load or flexure, the bone acquires an electrical charge, i.e., it has piezoelectrical properties. These facts are well confirmed by the presence in the bone of two intimately related crystalline systems -- crystals of hydroxyl apatite and crystals of collagen, which comprise the basic substance of the bone, its matrix. During load and flexures of the surfaces of these crystals, a certain differential of potentials appears, and the sources of this electricity can appear simultaneously at many points of adjacency of a vast number of crystals of hydroxyl apatite and collagen. The experimental investigations of Bassett (1965) showed that during deformation of the bone layer, on its surface an electrical charge is formed which is proportional to the force of deformation. Those regions of the bone which are subjected to the greatest deformation acquire a strict electrical polarity. During this process growth of bone is enhanced in the spot where negative charges dominate leading to the accumulation of osteoblasts. On the other hand, the places where positive charges develop are dominated by the presence of osteoclasts which lead to partial resorption of the bone tissue.

During weightlessness, apparently, a sharp decrease in electrical potential should occur in bones with a decrease in nutrition and oxygenation of the bone and predominance of functions of osteoclasts over functions of osteoblasts. The latter leads to breakdown of the bone structure, washing of calcium into the blood stream and accelerated elimination of calcium from the organism. Over a 7-8 week stay in weightlessness, approximately 5-7% of the calcium of bone tissue can vanish, and according to the calculations of I. S. Balakhovskiy et al. (1969), over 100 days up to 10% of all calcium can be removed. In these cases the danger of disruption in the stability of the bone can appear. This danger is particularly high in regions of the skeleton with increased metabolism, where resorption of bone occurs more intensively: in the trabecular and femoral bones, in the bones of the shin, in the vertebral bodies, and in the heel bone (Klapper; Mack, 1966; Mack, 1966; Vogt et al., 1965, and others).

The results of investigations obtained after the longest flight (22 days long) of two dogs aboard the Kosmos-110 spacecraft are evidence of the significant increase in elimination of calcium from the organism (Ye. N. Biryukov, 1967, 1968). In the blood of these dogs the content of calcium increased to 14.8-15.6% and a negative calcium balance was noted. When 430 mg calcium was /328
ingested with food in a one-day period, the total excretion of calcium in "Veterka" and "Ugol'ka" comprised 793 and 634 mg/day.

Disruptions of the calcium metabolism can also be linked with changes in coagulability of the blood after a stay in weightlessness. The latter actually occurred in dogs after flights aboard the Kosmos-110 spacecraft (Ye. N. Biryukov, 1968; N. N. Gurovskiy, A. A. Kiselev, 1968). It is important to emphasize that disorders of the calcium metabolism under these conditions, apparently, can be closely linked with changes in the protein and phosphorus metabolism. This link was clearly established during partial simulation of weightlessness under conditions of long term hypokinesis in the rat (Ye. A. Kovalenko et al., 1970; A. A. Prokhonchukov et al., 1970).

Gas energetic metabolism. Of course, one of the most significant and up to the present day least studied problems is that of change in gas energetic metabolism under conditions of weightlessness.

Elementary physical calculations clearly show that under conditions of space flight carrying out the same work as on the Earth requires extremely small energetic expenditures necessary merely to overcome the force of inertia. But at the same time, the production of energy in the organism has been tuned throughout the course of all life to another higher level. The necessity arises primarily of determining exactly what the new energy expenditures are in weightlessness and of demonstrating many already established classical calculations of energy loss of the organism.

It is possible that under these conditions one should reexamine the caloric value of the food ration. It is interesting that of 2,500 kcal of food, the American astronauts consumed only 1,465-1,649 kcal (Berry, 1969).

At the first stages of long term weightlessness, gradual detraining and asthenization of a number of systems of the organism can be compensated for well by a sharp decrease in energetic requirements. However, this in its turn leads to subsequent decrease in functions of the organism, i.e., a unique vicious circle can appear.

According to the data of P. K. Isakov et al. (1964), staying under conditions of short term weightlessness created during flights in aircraft along a ballastic trajectory caused a slight increase in pulmonary ventilation (from 8.4 to 8.9 liters/minute) in subjects. Simultaneously, an increase in the consumption of oxygen appeared (from 320 to 533 ml/min) as well as an increase in the elimination of CO_2 (from 260 to 412 ml/min).

At the XVIII International Astronautics Congress in Belgrad, I. I. Kas'yan et al. (1967), cited more detailed data on the characteristics of changes in external respiration and gas metabolism under conditions of short term weightlessness not only in a state of rest, but also when accomplishing various working operations. If in the original period oxygen consumption in six persons was within the limits of 214-330 ml/min, in weightlessness it comprised 306-549 ml/min.

However it is vital clearly to understand that these data were obtained under conditions of short term weightlessness for a period of 40-50 seconds and immediately after exposure to significant g-forces which preceded weightlessness. Therefore, to relate these data only to weightlessness is hardly expedient; they could sooner reflect the consequences of g-forces and the onset of an unusual period of entering weightlessness for the organism. Actually, the absence of coordination of movement, the influence of inertial, at first poorly regulated moments of movement during complex work can lead even to a significant increase in gas metabolism and energy expenditures. Only in subsequent prolonged stages of staying in weightlessness can the earlier stated basic characteristics of decrease in requirements for energy expenditures of the organism and significant changes in gas metabolism be manifested. /329

Berry et al. (1967), calculated average energy expenditures according to excreted carbon dioxide in astronauts. In the flight of Gemini-4 these comprised 2,400 kcal/day, Gemini-5 -- 2,010 kcal, Gemini-7 -- 2,219 kcal/day. It turned out that the calculated approximate energy expenditures were greater than the caloric content of the food actually eaten. Naturally, under such conditions weight loss occurred in the first stage and amounted to 2-3.8 kg, in the second stage 3.4-3.8 kg, and after the flight aboard Gemini-7 -- 2.7--4.5 kg. According to the data of Berry, the same thing was also observed among the crew members of Apollo-8. Berry et al. (1966, 1967, 1969, 1970) consider that a certain tendency is noted to a decrease in energy expenditures proportional to an increase in the duration of flight under conditions of weightlessness. If during short term flights aboard the Mercury spacecraft energy expenditures comprise nearly 126 kcal, on the 8-day flight aboard the Gemini-5 spacecraft they comprised about 75.6 kcal.

On the basis of an investigation of results following flight processing of regenerated substances of the life support systems and dynamic changes in the concentration of oxygen, carbon dioxide, and H_2O in the cabin air of spacecraft, A. M. Genin, G. I. Voronin, and A. G. Fomin (1965) concluded that conditions of spaceflight do not exert a great influence on human energy expenditures during short term flights. Mean hourly energy expenditures during these flights comprised the following: for A. G. Nikolayev -- 85.8 kcal/hour, for P. R. Popovich -- 97.2, for V. V. Tereshkova -- 83.5, for V. F. Bykovskiy -- 84.6 kcal/hour.

The data of these authors also confirm the earlier expressed viewpoint of the gradual decrease in energy expenditures in weightlessness, although at first they can even be heightened.

Extremely interesting data were obtained by Wortz and Presscott (1966), during an investigation of human energy expenditures in a special training device which on the Earth simulates diminished gravitation (1/4, 1/6 and 1/8 terrestrial gravitation). When a man walks on a treadmill installed in this training device at a rate of 6.4 km/hour, energy expenditures decreased by 48, 56 and 60% respectively from the original value. As one can see, these changes are extremely significant and directly depend upon the decrease in gravitation; consequently, even on the Moon where the magnitude of gravity is 1/6 terrestrial gravity, a decrease in energy expenditures can occur at a level greater than 50%. These data to a known degree were confirmed by direct measurement of energy expenditures during the landing of astronauts on the Moon; they turned out to be lower than the assumed level notwithstanding work in the space suit.

Interesting data on gas metabolism under conditions of actual spaceflight were obtained from P. I. Belyayev and A. A. Leonov (I. I. Kas'yan, V. I. Kopanev, 1967). For A. A. Leonov consumption of oxygen increased by 206 ml/min, which is entirely understandable in connection with the high stress and accomplishing certain working operations (entering open space). For P. I. Belyayev, consumption of oxygen decreased by 72 ml/min, in comparison with the original preflight data. The latter to a known degree confirms the earlier expressed hypothesis concerning a decrease in metabolism in weightlessness.

Unfortunately, these unique data are at present extremely few and it is at present early to make a final conclusion.

One can think that with a long term decrease in energy expenditures under the effect of weightlessness, without corresponding protective measures, detraining of circulation and respiration could ensue.

REFERENCES

Bayevskiy, R. M. and P. G. Gazenko, "Reaction of the Human Cardiovascular System and the Cardiovascular System of Animals to Weightlessness," *Kosmich. Issled.*, Vol. 2, No. 6, pp. 307, 1964.

Berry, C. A., "Gemini Biomedical Results," XVII Congress of the International Astronautical Federation, Madrid, pp. 43, 1966.

Berry, C. A., "Preliminary Clinical Report of the Medical Aspects of Apollos VII and VIII," *Aerospace Med.*, Vol. 40, pp. 245, 1969.

Berry, C. A., "Summary of Medical Experience in the Apollo 7 through 11 Manned, Spaceflights," *Aerospace Med.*, Vol. 41, pp. 500, 1970.

Berry, C. A. and A. D. Catterson, "Pre-Gemini Medical Predictions Versus Gemini Flight Results," *The Final Gemini Summary Conference Publication*, 1967.

Besset, A., "Electrical Phenomena in the Bones," in the book: *Molekuly i Kletki* [Molecules and Cells], Moscow, 2nd Edition, pp. 119, 1967.

Bugrov, B. T., O. G. Gorlov and A. V. Petrov, "Investigations of the Vital Activity of Animals During Flights in a Nonhermetically Sealed Rocket Cabin to an Altitude of 110 km," in the book: *Predvaritel'nyye Itogi Nauchnykh Issledovaniy s Pomoshch'yu Pervykh Sovetskikh Iskusstvennykh Sputnikov Zemli i Raket* [Preliminary Results of Scientific Investigations by the Aid of the First Soviet Artificial Satellites of the Earth and Rockets], Moscow, Academy of Sciences USSR, pp. 130, 1958.

Busdy, D. E., "Space Biomagnetics," *Space Life Sci.*, Vol. 1, pp. 23, 1968.

Chekirda, N. F., L. V. Chkhaidze and I. A. Kolosov, "Simulating Human Movements in Weightlessness and in Aqueous Medium with Biomechanical Position," *Izv. AN SSSR. Seriya Viol.*, Vol. 3, pp. 334, 1969.

Chizhevskiy, A. L. and Yu. G. Shishina, *V Ritme Solntsa* [In the Rhythm of the Sun], Moscow, 1969.

Dietlein, L., "Effect of Weightlessness During Manned Space Flight Under Study by NASA," *Electronic News*, Vol. 9, No. 4, pp. 440, 442, 443, 1964.

Gauer, O. H., P. Eckert and D. Kaiser et al., "Fluid Metabolism and Circulation During and After Simulated Weightlessness," in the book: *Second International Symposium on Basic Environmental Problems of Man in Space*, Paris, pp. 212, 1965.

Gazenko, O. G., "Certain Problems of Space Biology," *Vestn. AN SSSR*, No. 1, pp. 30, 1962.

Gazenko, O. G. and A. A. Gyurdzhian, "Physiological Effects of Gravitation," In the book: *Problemy Kosmicheskoy Biologii* [Problems of Space Biology], Moscow, Vol. 6, pp. 22, 1967.

Genin, A. M., G. I. Voronin and A. G. Fomin, "Physiological Hygienic Evaluation of Life Support Systems of the Vostok, Voskhod Spacecraft," Report given at the Second International Symposium on Basic Problems of Human Life In Outer Space, Paris, 1965.

Goodall, M. C., M. McCally and D. E. Graveline, "Urinary Adrenaline and Noradrenaline Response to Simulated Weightless State," *Am. J. Physiol.*, Vol. 206, pp. 431, 1964.

Gurfinkel', V. S., P. K. Isakov, V. B. Malkin and others, "Coordination of Posture and Movements of Man in Conditions of Increased and Decreased Gravitation," in the book: *Mediko-Biologicheskiye Issledovaniya v Nevesomosti* [Medical-Biological Investigations in Weightlessness], Moscow, Vol. 355, 1968.

Gurovskiy, N. N. and A. A. Kiselev, *Fiziologicheskiye Problemy Dlitel'noy Nevesomosti* [Physiological Problems of Long Term Weightlessness], Report given at the Third International Symposium on Basic Problems of Human Life in Outer Space, UNESCO, VOZ, Geneva, 1968.

Hattner, R. S. and D. E. McMillan, "Influence of Weightlessness Upon the Skeleton: A Review," *Aerospace Med.*, Vol. 39, pp. 849, 1968.

Hauty, G. T., "Physics and Medicine of the Atmosphere and Space," Edited by O. O. Benson and H. Strughold, J. Wiley and Sons, Inc., New York-London, pp. 409, 1960.

Hood, W. B. et al., "Circulatory Effects of Water Immersion Upon Human Subjects," *Aerospace Med.*, Vol. 39, pp. 579, 1968.

Howard, P., J. Ernsting, D. M. Denison et al., "Effects of Simulated Weightlessness Upon the Cardiovascular System," *Aerospace Med.*, Vol. 38, pp. 551, 1967.

Isakov, P. K., Ye. M. Yuganov and I. I. Kas'yan, "Gravitational Effects in Forming the Functions of the Organism," *Izv. AN SSSR. Seriya Biol.*, pp. 913, 1964.

Kas'yan, I. I., V. I. Kopanev and V. I. Yazdovskiy, "Circulation Under Conditions of Weightlessness," *Izv. AN SSSR. Seriya Biol.*, Vol. 3, pp. 352, 1964.

Kas'yan, I. I., A. S. Krasovskiy, I. A. Kolosov and others, "Certain Physiological Reactions of Man Under Conditions of Short Term Weightlessness," *Izv. AN SSSR. Seriya Biol.*, Vol. 5, pp. 633, 1965.

Kas'yan, I. I., I. A. Kolosov, V. I. Kopanev and others, "Physiological Reactions of Cosmonauts in Unsupported Space," *Izv. AN SSSR, Seriya Biol.*, Vol. 1, pp. 3, 1966.

Kas'yan, I. I., G. F. Makarov, I. P. Neumyvakin and others, "Changes in the Indices of External Respiration, Gas Metabolism and Energy Expenditures of Man Under Conditions of Weightlessness," *Izv. AN SSSR. Seriya Biol.*, Vol. 1, pp. 20, 1969.

Kerpel'-Fronius, E., *Patologiya i Klinika Vodno-Solevogo Obmena* [Pathology in Clinics of the Water-Salt Metabolism], Budapest, 1964.

Klosovskiy, B. H. and Ye. N. Kosmarskaya, *Deyatel'noye i Tormoznoye Sostoyaniye Mozga* [The Active and Inhibited Condition of the Brain], Moscow, 1961.

Komendantov, G. L. and V. I. Kopanev, "Roll as a Problem of Space Medicine," in the book: *Problemy Kosmicheskoy Biologii* [Problems of Space Biology], Moscow, Academy of Sciences USSR, Vol. 2, pp. 80, 1962.

Kovalenko, Ye. A., V. L. Popkov, Yu. I. Kondrat'yev and others, "Change in the Function of the Organism During Long Term Hypokinesis," *Pat. Fiziol.*, Vol. 6, pp. 3, 1970.

Kovalenko, Ye. A., A. A. Prokhonchukov, A. G. Kolesnik, R. V. L'vov, Yu. I. Kondrat'yev, and Yu. S. Galushko, "Mechanism of Disorders of Mineral Metabolism in Decalcinated Skeletal Tissues During Experimental Hypodynamia," in the book: *Trudy 1-y Respublikansk. Nauchno-Tematicheskoy Konferentsii po Stomatologicheskoy Anatomii* [Transactions of the 1st Republican Scientific Thematic Conference on Stomatological Anatomy], Moscow, 1970.

Kovalenko, Ye. A., Yu. I. Kondrat'yev, I. A. Abakumova and others, "Study of Adaptation of the Organism of the Rat to Conditions of Long Term Hypokinesis," in the book: *Adaptatsiya k Myshechnoy Deyatel'nosti i Gipokineziya* [Adaptation to Muscular Activity in Hypokinesis], Novosibirsk, pp. 87, 1970.

Kovalenko, Ye. A., V. L. Popkov, E. S. Mailyan and others, "The Effect of Hypodynamia on the Gas Metabolism of Animals," *Kosmich. Biol. i Med.*, Vol. 4, pp. 3, 1971.
Korobkov, A. V., "The Development and Maintenance of a High Level of Motor Function as a Problem in Preparing and Accomplishing Long Term Space Flights," in the book: *Aviatsionnaya i Kosmicheskaya Meditsina* [Aviation and Space Medicine], Moscow, pp. 28, 1963.
Kovit, B., "Man in Orbit," *Space (Aeronautics)*, Vol. 41, pp. 76, 1961.
Lamb, L. E., "An Assessment of the Circulatory Problem of Weightlessness in Prolonged Space Flight," *Aerospace Med.*, Vol. 35, pp. 413, 1964.
Lamb, L. E., "Hypoxia -- An Anti-Deconditioning Factor for Manned Space Flight," *Aerospace Med.*, Vol. 36, No. 2, pp. 97, 1965.
Lynch, T. N., R. L. Jensen and P. M. Stevens, "Metabolic Effects of Prolonged Bed Rest: Their Modification by Simulated Altitude," *Aerospace Med.*, Vol. 38, pp. 10, 1967.
McCally, M., S. A. Pohl and P. A. Samson, "Relative Effectiveness of Selected Space Flight Deconditioning Countermeasures," *Aerospace Med.*, Vol. 39, pp. 722, 1968.
Morris, R. W. and L. R. Kittleman, "Piezoelectric Property of Otoliths," *Science*, Vol. 158, pp. 368, 1967.
Moskalenko, Yu. Ye., *Dinamika Krovenapolneniya Golovnogo Mozga v Norme i Pri Gravitatsionnykh Nagruzkakh* [Dynamics of Blood Content of the Brain in the Norm and During Gravitational Loads], Leningrad, 1967.
Myasnikov, A. L., R. M. Akhrem-Akhremovich, L. I. Kakurin and others, "The Problem of the Influence of Long Term Hypokinesis on Human Circulation," in the book: *Aviatsionnaya i Kosmicheskaya Meditsina* [Aviation in Space Medicine], Moscow, pp. 368, 1963.
Parin, V. V., Yu. M. Volynkin and P. V. Vasil'yev, "The Flight of Man in Space," Materials of a Symposium, Florence, 1964.
Prokhonchukov, A. A., Ye. A. Kovalenko, A. G. Kolesnik, Yu. I. Kondrat'yev and N. A. Il'yushko, "The Effect of Hypodynamia on the Mineral and Protein Metabolism in Decalcinated Tissues of the Tooth-Jaw System," *Stomatologiya*, Vol. 4, pp. 1, 1970.
Sisakyan, N. M., *Vtoroy Gruppovoy Kosmicheskiy Polet i Nekotoryye Itogi Poletov Sovetskikh Kosmonavtov na Korablyakh "Vostok". Mediko-Biologicheskiye Issledovaniya* [The Second Group Space Flight in Certain Results of Flights of Soviet Cosmonauts Aboard the Vostok Spacecraft. Medical-Biological Investigations], "Nauka" Press, Moscow, 1965.
Vasil'yev, P. V., A. D. Voskresenskiy and I. I. Kas'yan et al., "Reactions of the Cardiovascular and Respiratory Systems of Cosmonauts Under Conditions of Orbital Flight Aboard the Voskhod-1 Spacecraft," *Izv. AN SSSR. Seriya Biol.*, Vol. 4, pp. 491, 1965.
Vogt, F. B. and P. C. Johnson, "Plasma Volume and Extracellular Fluid Volume Change Associated with 10 Days Bed Recumbency," *Aerospace Med.*, Vol. 38, pp. 21, 1967.
Vorob'yev, Ye. I., Yu. G. Nefedov and L. I. Kakurin et al., "Medical Investigations Carried Out During the Flights of the Soyuz-3, Soyuz-4 and Soyuz-5 Spacecraft," *Kosmich. Biol. i Med.*, Vol. 3, No. 4, pp. 46, 1969.
Vorob'yev, Ye. I., A. D. Yegorov and L. I. Kakurin et al., "Medical Support and Basic Results of an Investigation of the Crew of the Soyuz-9 Spacecraft," *Kosmich. Biol. i Med.*, Vol. 4, No. 6, pp. 26, 1970.

Vorob'yev, Ye. I., Yu. G. Nefedov and L. I. Kakurin, "Certain Results of Medical Investigations Carried Out During the Flights of the Soyuz-6, Soyuz-7 and Soyuz-8 Spacecraft," *Kosmich. Biol.*, Vol. 4, No. 2, pp. 65, 1970.
Webb, F., "Silicone Submersion -- A Feasibility Study," *U.S. Naval Air Development Center*, pp. 56, October, 1966.
Wortz, E. C. and E. J. Prescott, "Effects of Subgravity Traction Simulation on the Energy Costs of Walking," *Aerospace Med.*, Vol. 37, pp. 1217, 1966.
Yazdovskiy, V. I., "Basic Stages in the Development of Space Biology and Medicine in the USSR," in the book: *Kosmicheskaya Biologiya i Meditsina* [Space Biology and Medicine], Moscow, pp. 68, 1966.
Yegorov, A. D. and L. I. Kakurin, "Mechanism of Changes in Physiological Reactions in Space Flight," in the book: *Aviatsionnaya i Kosmicheskaya Meditsina* [Aviation and Space Medicine], Moscow, pp. 57, 1969.
Yeremin, A. V., I. I. Kas'yan, I. A. Kolosov and others, "Human Working Capacity Under Conditions of Weightlessness," *Izv. AN SSSR. Seriya Biol.*, Vol. 3, pp. 329, 1965.
Yuganov, Ye. M., I. I. Kas'yan and B. F. Asyamolov, "Bioelectrical Activity of the Skeletal Musculature Under Conditions of Changing Effects of g-Forces and Weightlessness," *Izv. AN SSSR. Seriya Biol.*, Vol. 5, pp. 746, 1963.
Yuganov, Ye. M., I. A. Sidel'nikov, A. I. Gorshkov and others, "Sensitivity of the Vestibular Analyzer and Sensory Reactions of Man During Short Term Weightlessness," *Izv. AN SSSR. Seriya Biol.*, Vol. 3, pp. 369, 1964.
Yuganov, Ye. M., A. I. Gorshkov, I. I. Kas'yan and others, "Vestibular Reactions of Cosmonauts During Flight Aboard the Voskhod Spacecraft," *Izv. AN SSSR. Seriya Biol.*, Vol. 6, pp. 877, 1965.

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